REPORT 33

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

DEVELOPMENT OF A COMPUTER-BASED FARM DECISION SUPPORT FRAMEWORK PHASE I

FINAL REPORT

October, 1991

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On Behalf of:	AGRICULTURE CANADA RESEARCH STATION, HARROW, ONTARIO N0R 1G0

Contents

Figures and Graphs

Report on the Farm Management Framework Project Phase I

Robert Hoffman
Bert McInnis

April 23, 1991

1. Introduction

This is the final report on Phase I of the project undertaken by ROBBERT Associates as part of the Technology Evaluation and Development (TED) Sub-Program of the Soil and Water Environmental Enhancement Program (SWEEP). The project consisted of the design and implementation of a prototype computer based farm management simulation framework that can be used at the level of the individual farm to examine the impact of tillage and cropping decisions on soil quality, nutrient loss to runoff, and farm income. The objective was to determine whether modelling techniques might be useful to effect the transfer of technology from the scientific community to the farm.

2. Project structure

The project was carried out by Michael Hoffman, Robert Hoffman and Bert McInnis of ROBBERT Associates working with an advisory group consisting of Bob Fletcher, Dave Charlton and George Schell of Ecological Services for Planning, Don Lobb and Doug Smith both farmers, Wally Findlay of Agriculture Canada, and John Schleihauf from the Ontario Ministry of Agriculture and Food.

The project commenced in June, 1990 and was concluded in March 1991. The advisory group met on four occasions with ROBBERT Associates, July 13, 1990, November 29, 1990, March 27, 1991, and April 11, 1991. Both the April and March meetings involved interaction with the computer system.

A poster presentation was displayed at the TED - Tillage 2000 Conference held in London on March 4-5, 1991. A copy of the handout that accompanied the poster is appended to this report.

3. Structure of the Farm Management Framework

The structure of the Farm Management Framework (FMF) is documented in the FMF Manual, (Ref 10). The Farm Management Framework consist of fifteen calculators or independently executable submodels organized in a hierarchy composed of five major components:

- **Cropping** component that represents all aspects of crop production including soil productivity - crop relationships;
- **Livestock** component that represents all aspects of the production of dairy and livestock products;

- **Crop and Manure Balance** component that keeps track of the interdependence between cropping and livestock operations

- **Equipment** component that keeps track of the equipment needed for field operations and its utilization in terms of operator time and fuel

- **Farm Finance** component that represents the elements farm income and outlay separately for cropping and livestock operations and a capital expenditures account.

The full hierarchy is shown in Figure 1. The interdependence among the calculators is shown the Dependency Structure diagram, Figure 2.

The Framework is designed to simulate farm operations to a time horizon of fifty years from the present. Calculations are performed with a one year time-step.

The FMF focuses on the 'farm' as the unit of analysis. A farm consists of a number of fields, stocks of equipment and livestock. Each field is characterized by size, topography, soil composition, and top soil depth. The FMF is generic in the sense that it can be applied or adapted to any specific farm. In effect, a version of the model unique to each farm is generated through the process of calibration, and a history is created which reflects the conditions of the specific farm. The scale of the farm is potentially important in determining the economic viability of the farm.

The FMF focuses on the longer term dynamics of farm management, accordingly the time horizon is 30 - 50 years into the future and calculations are carried out in one year time steps. It is intended to support the analysis of alternative farm management strategies. A farm management strategy consists of a combination of choices with respect to crop or crop rotation, tillage practice, and livestock in terms of the number of animals and management strategy. Each strategy is analysed in terms of farm income, the evolution of the state of the soil as indicated by organic content and productivity, and loss of nutrients in run-off. The FMF is not intended to support the analysis of the vulnerability or sensitivity of farm management strategies to abnormal weather conditions nor the implications of adaptive farm management decisions (decisions that are taken during the course of a year or growing season in response to events that are particular to that year). Thus, the FMF abstracts from daily weather fluctuations that give rise to stress factors that inhibit plant growth; furthermore, it is assumed that the required nutrients will actually be applied and the amounts of nutrients required are calculated.

The state of the soil is indicated by its composition by dry weight - the components being sand, silt, clay, coarse fragments, fresh organic content, humic organic content, all measured in kg per kg of soil at the end of each growing season. The active dynamic soil components are organic content. Fresh organic content consists of plant roots and the share of above ground plant material that is incorporated into the soil. Fresh organic content is transformed into humic organic content by the process of decomposition; organic content is lost through the process of vaporization. The rates of decomposition and vaporization are affected by cropping and tillage practices. The soil evolution model is a set of linear difference equations that keep track of flows of organic material into and out of four separate pools: above ground residue, residue incorporated into the soil, root material, and humus. (See Figure 3). Humic organic content is important because humus promotes nutrient cycling and the release of nutrients in a form and at a rate that is commensurate with the rate of plant uptake. Furthermore, humic content increases the propensity of the soil to retain moisture and enhances soil structure.

Figure 1

Farm Management Framework

HIERARCHY

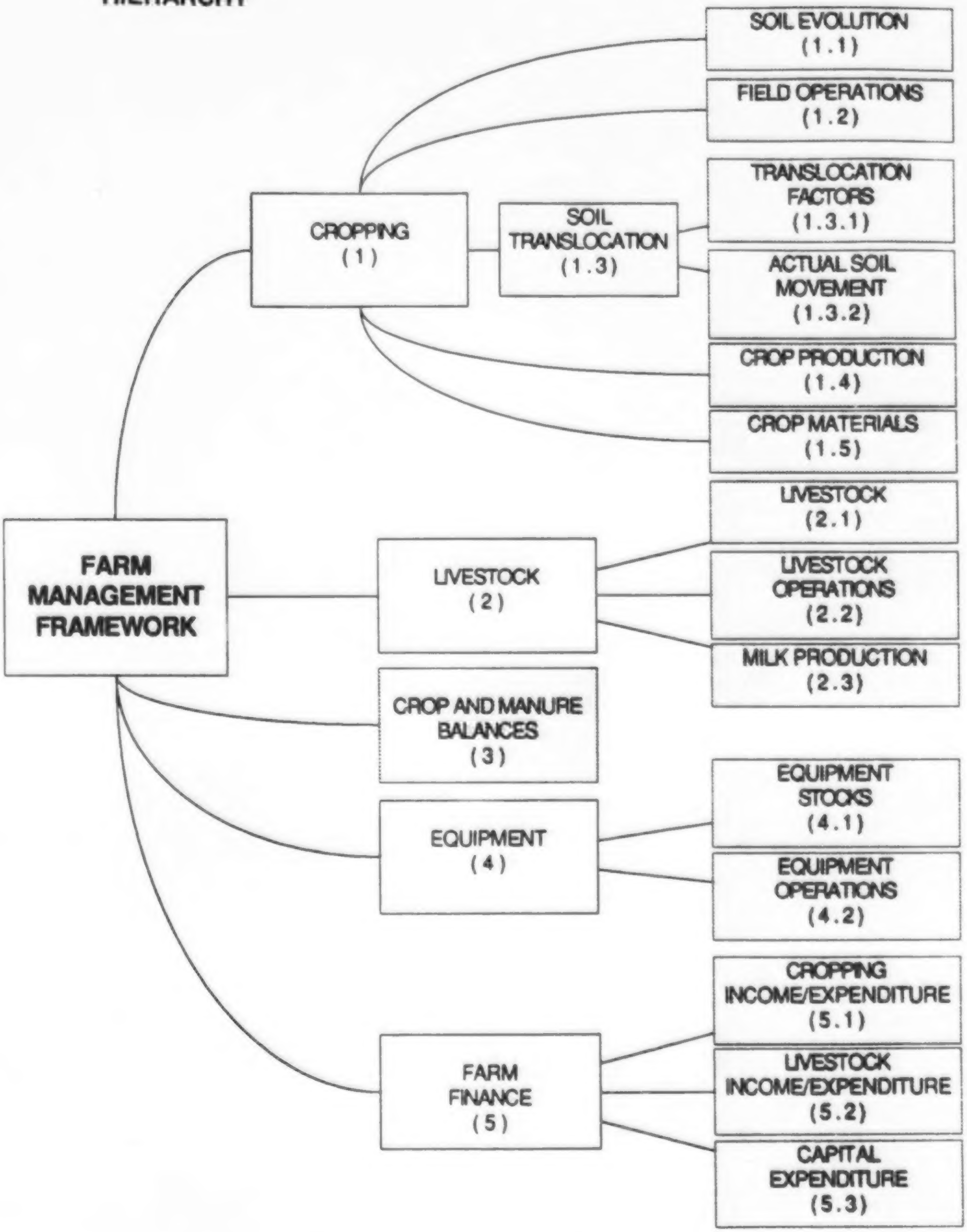


Figure 2

Farm Management Framework

DEPENDENCY STRUCTURE

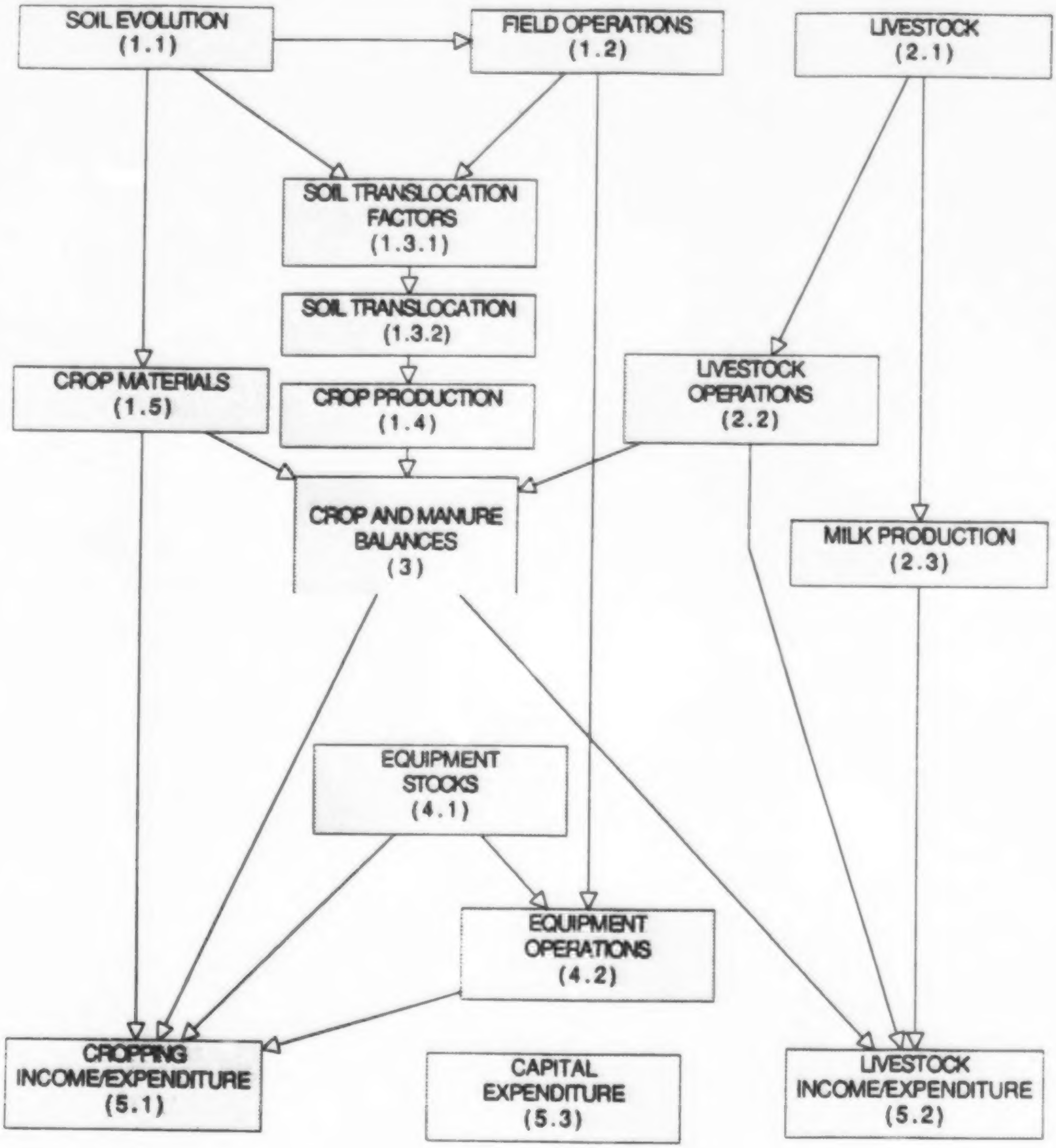
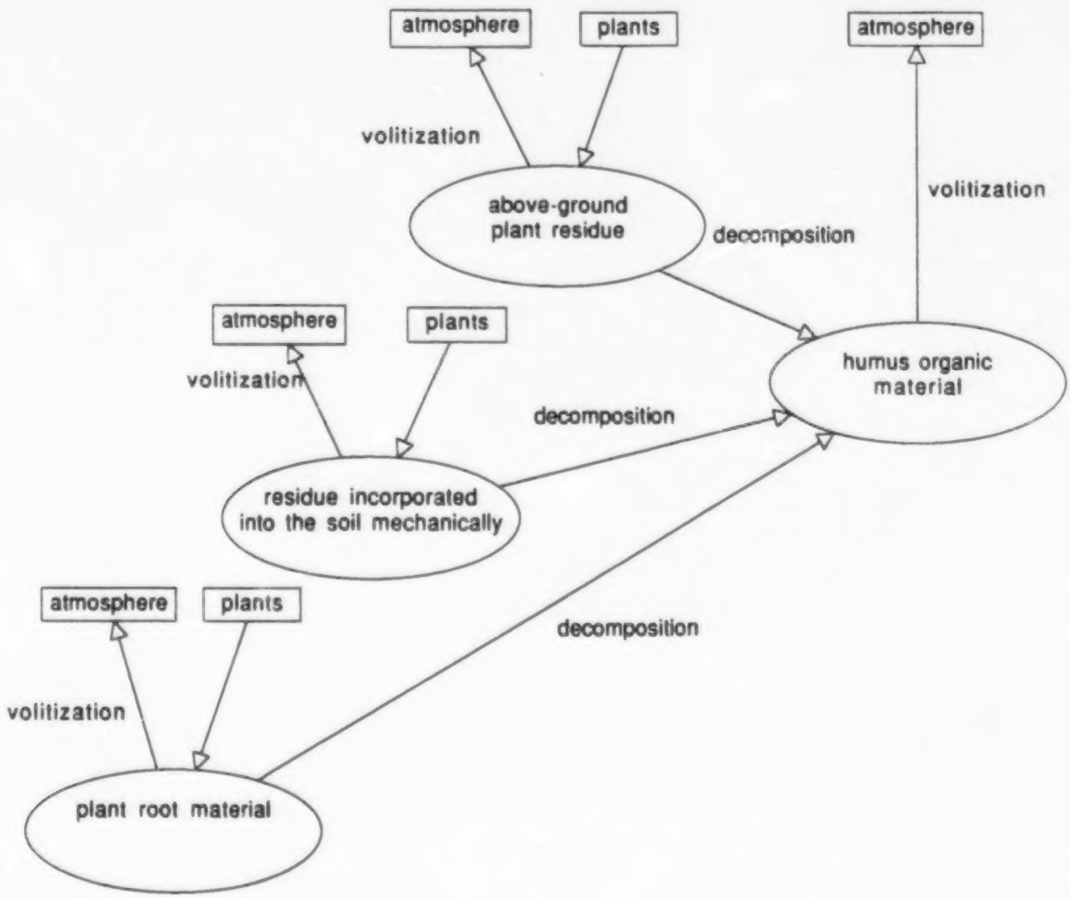


Figure 3

STOCKS AND FLOWS OF ORGANIC MATERIAL



An important feature of the FMF is the treatment of soil movement from erosion and cultivation and the resulting yield losses. The FMF includes a Soil Translocation Calculator (1.3) which is capable of representing soil movement on fields with complex topography. This is important because recent research has found severe yield losses from the shoulders of slopes in the field. Each field is divided into ten metre squares characterized by top soil depth, elevation, slope, and its location relative to other squares. Soil loss or movement is indicated in terms of change in soil depth. The relationship between soil depth and yield is represented as non-linear so that yields will fall once a threshold soil depth has been reached. Thus, as soil movement occurs the areas subject to yield reduction increase over time and the average yield of the field is reduced. The rate of soil translocation will depend upon the tillage practice, the amount of coverage provided by plants and plant residue, and the state of the soil. Soils with coverage, either residue or plants particularly during early spring, will suffer less soil movement than bare soils that are low in organic content. Soil movement due to cultivation, rainfall energy, and water flow are explicitly represented.

4. Implementation

The Farm Management Framework (FMF) was implemented using the ROBBERT Associates Decision Support Tools on a Macintosh A/UX micro computer system. Several features are worth noting:

The relationships of the model are expressed as TOOL language statements, which have the syntax of a stylized subscripted algebra. The TOOL language statements are executable computer programs. Thus, the correspondence between the mathematical statement of the model and the programs that realize it is assured.

Documentation is the first step in implementation; the data structures and files needed for implementation are created by processing the manual. The only way to change a model is to change the documentation, thereby assuring that documentation is up-to-date.

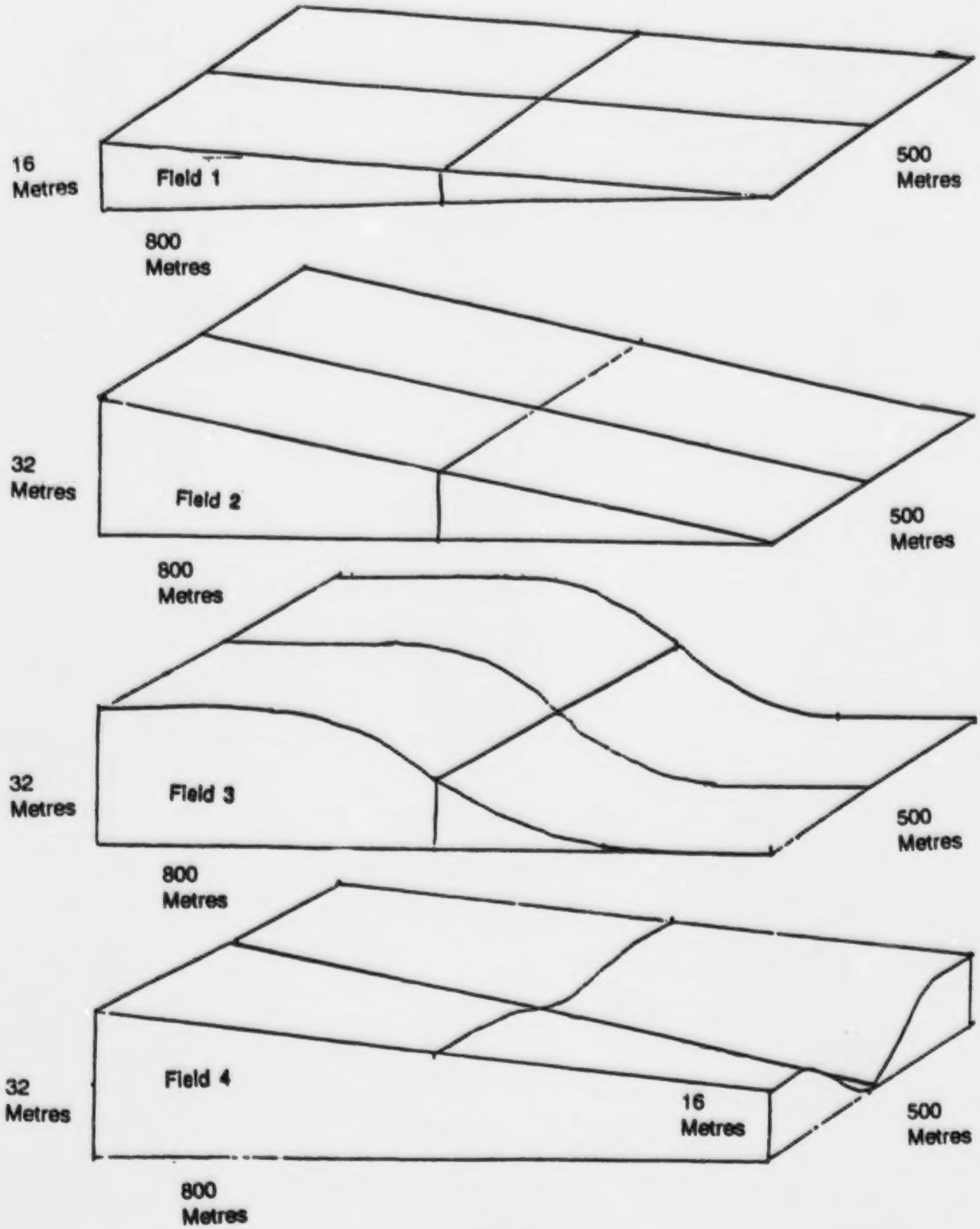
All of the data associated with the FMF are handled as data files; there are no numerical constants embedded in the computer code.

5. Calibration

For the purpose of demonstrating the framework to members of the advisory group, data for the model were assembled from a variety of sources including information from members of the committee. The data were intended to be representative rather than definitive.

An "artificial" farm consisting of four 40 hectare, (approximately 100 acre), fields was created. All four fields were given the same soil, namely a heavy clay-loam soil, with low (5%) organic content and all four were the same size, 800 metres by 500 metres. However, the fields differed by topography as shown in Figure 4: field 1 was flat with a 2% slope; field 2 was flat with a 4% slope; field 3 was given a shoulder running across the middle of the field; field 4 was given a trough running down the middle of the field with the trough falling on a 4% slope and two shoulders on either side of the trough. Field topographies are illustrated on the accompanying diagram. Graphs 1 and 2 show the lengthwise and widthwise cross sections at mid field respectively.

Figure 4
Field Topographies



The parameters of the difference equations governing the evolution of organic content were calculated so that the maximum organic content for this soil was 12% and the minimum was 5%. A field in meadow would reach the maximum value and maintain organic content at that level. If meadow were cultivated and planted with continuous corn using conventional tillage, organic content would fall to the minimum value in about ten to fifteen years.

Data on yields, seeding rates, fertilization rates, plant masses, plant densities were taken from the 1991-1992 Field Crop Recommendations published by OMAF (Ref 6) and the EPIC model data base (Ref 9) and supplemented by estimates made by thee project team as required. Data on crop prices were the five year averages published in Ontario Farm Management Analysis Project 1989 by OMAF (Ref 2). Data on input prices were taken from the same source.

The data on yield as a function of soil depth reflected the assumption that maximum yields are obtained at soil depths of 30 centimetres and greater and minimum yields of 33% of the maximum yield are obtained at soil depths of 10 centimetres or less with an S-shaped curve in between.

The parameters expressing soil movement propensities were arbitrarily chosen in order to demonstrate the mechanics of soil movement on the four fields.

Representative data on machine passes by crop type and tillage type were provided by the advisory group as were data on the relative soil movement propensity of various machine types.

6. Sample Output from the Framework

Sample output from the framework was generated from two scenarios that were created to for the purpose of demonstration. The first scenario grows corn continuously on all four fields using conventional moldboard tillage; the second grows corn underseeded with rye on all four fields using no-till cultivation.

Graph 3 shows gross farm income for the two scenarios. The decline in gross income over time is attributable to yield loss from erosion. Note that the decline is much more pronounced under conventional tillage.

Graph 4 shows total operating expenditures for the two scenarios. Under conventional tillage, operating expenditures are constant over time; under no-till, operating expenditures decline over time as organic content increases and fertilizer requirements decrease. This effect is undoubtedly exaggerated in the data used for calibration.

Graph 5 shows net farm income which is the difference between gross income and total expenditures.

Graphs 6 and 7 show organic concentrations for the two scenarios respectively. In scenario 1, (Graph 6), humic organic concentration stays at the asymtotic minimum of 4%; in scenario 2, (Graph 7), humic organic concentration builds up over the simulation period to 8%; after 25 years the rate of increase begins to decline. Note that the organic concentrations are the same for all four fields.

Graphs 8 to 11 show average yields under the two scenarios for each of the four fields respectively. The changes in average yields are attributable to yield losses in the parts of the field that experience soil loss due to erosion and cultivation. Yield losses are most pronounced under conventional tillage in fields 3 and 4 which are the most contoured.

Graph 12 shows yield as a function of soil depth.

Graph 13 shows top soil depth over time for field 3 for scenario 1. At the beginning of the scenario, top soil depth was 30 centimetres at all points in the field; by the end of the scenario as much as ten centimetres has been lost from the shoulder of the field.

Graph 14 shows top soil depth over time for field 4 for scenario 1 at a cross section half way down the field. It shows soil loss from the shoulders on both sides of the valley, an accumulation of soil on the valley floor, and the formation of a gully running down the centre of the valley with ridges on either side of the gully.

Graph 15 shows top soil depth on field 4 at the end of the simulation period at three cross sections in the field. The first cross section at the top of the field shows constant top soil depth at 30 centimetres; the second cross section half way down the field shows top soil loss on the shoulders; the third cross section at the bottom of the field shows greater top soil loss on the shoulders. It is interesting to note that the gully is narrower at the bottom of the field.

7. Improvements in Model Structure

The final meeting of the advisory group resulted in the identification of a number of improvements in the structure of the framework that could be made:

- separate treatment for nitrogen with a set of difference equations to keep track of sources and sinks of nitrogen and with plant differentiation (legumes / non-legumes)

- addition of potassium as a nutrient to be treated analogously to the treatment of phosphorus

- additional equations to keep track of soil water retention propensities as a function of other variables in addition to organic content

- modification of the structure of the yield loss equations to respond to topsoil - subsoil mixing rather than top soil depth

- introduction of machine speed in the soil translocation equations

- change measure of of residue cover from kilograms per square metre to % cover

- add sufficient structure to treat crops with an underseeded crop as a combination of two separate crops.

- add a non-linear response in soil movement by water erosion to intensity of rainfall events

8. Future Work

First of all, the prototype should be thoroughly evaluated by the scientific community, agricultural policy analysts, farm extension workers, and farmers. Should the evaluation warrant further development two phases of activity can be identified.

Phase II of the development of the Farm Management Framework should include the following tasks:

(a) Implementation of the improvements in the structure of the model outlined above.

(b) Incorporation of better scientific data including data on plant characteristics such as plant mass, ratios of carbon to nitrogen, nutrient uptake, yields, and data on soil translocation from the cesium measurement program.

(c) Calibration of the model using data from a small number of farms. This calibration might include the following tasks:

Task 1: One day workshop to demonstrate prototype model to the participating farmers and to explain data requirements.

Task 2: Field data collection - one day meeting with each farmer at the farm site to identify and collect farm specific data.

Task 3: Incorporation and calibration of farm specific data with scientific data into existing model structure.

Task 4: A series of half day meetings, one with each farmer, for the purpose of demonstrating model use and providing results to each farmer

Task 5: Preparation of final report summarizing the project experience and outlining further research.

Phase III would be concerned with establishing an appropriate institutional framework to support widespread use.

References

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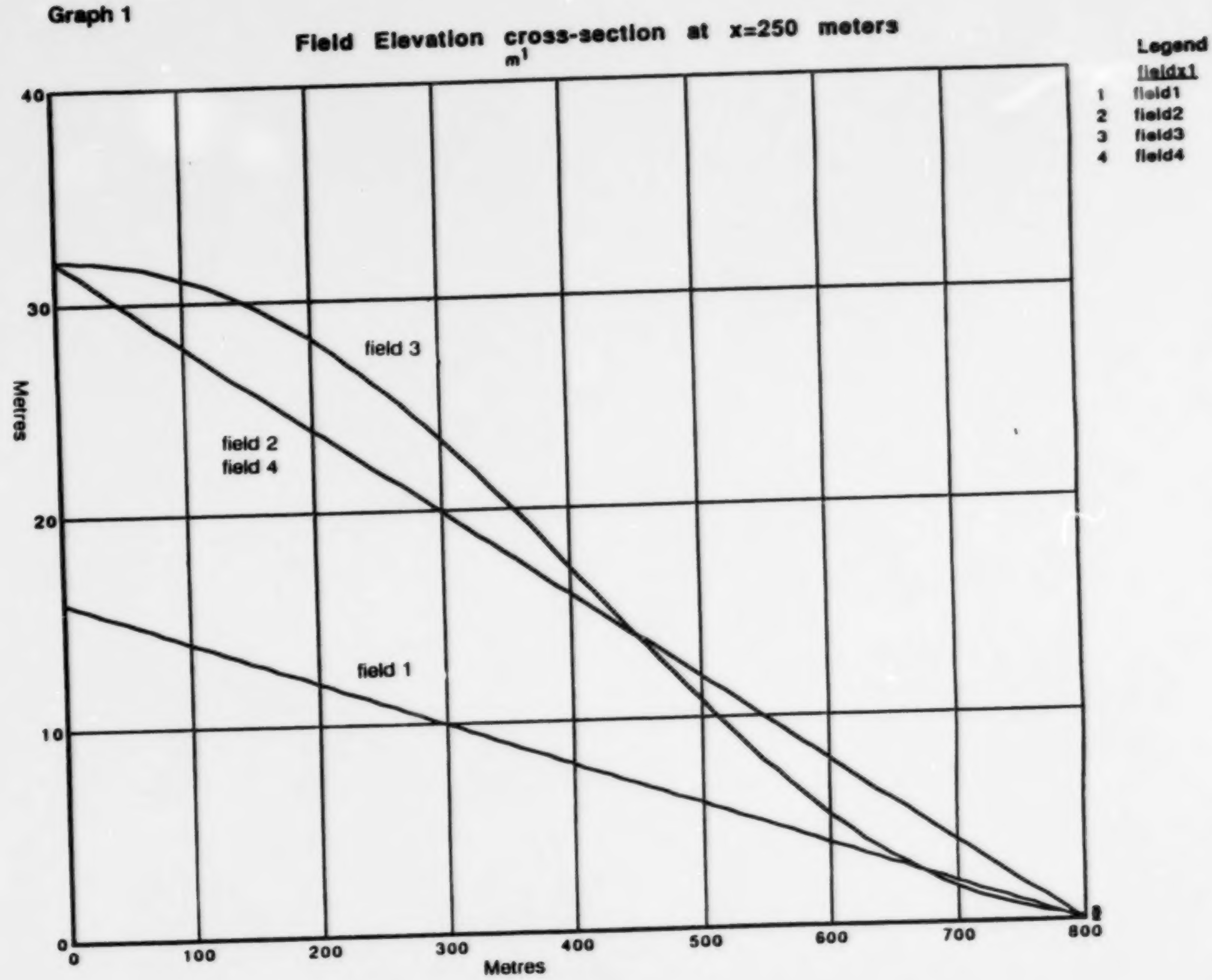
10. ROBBERT Associates. Farm Management Framework Manual. February 1991.

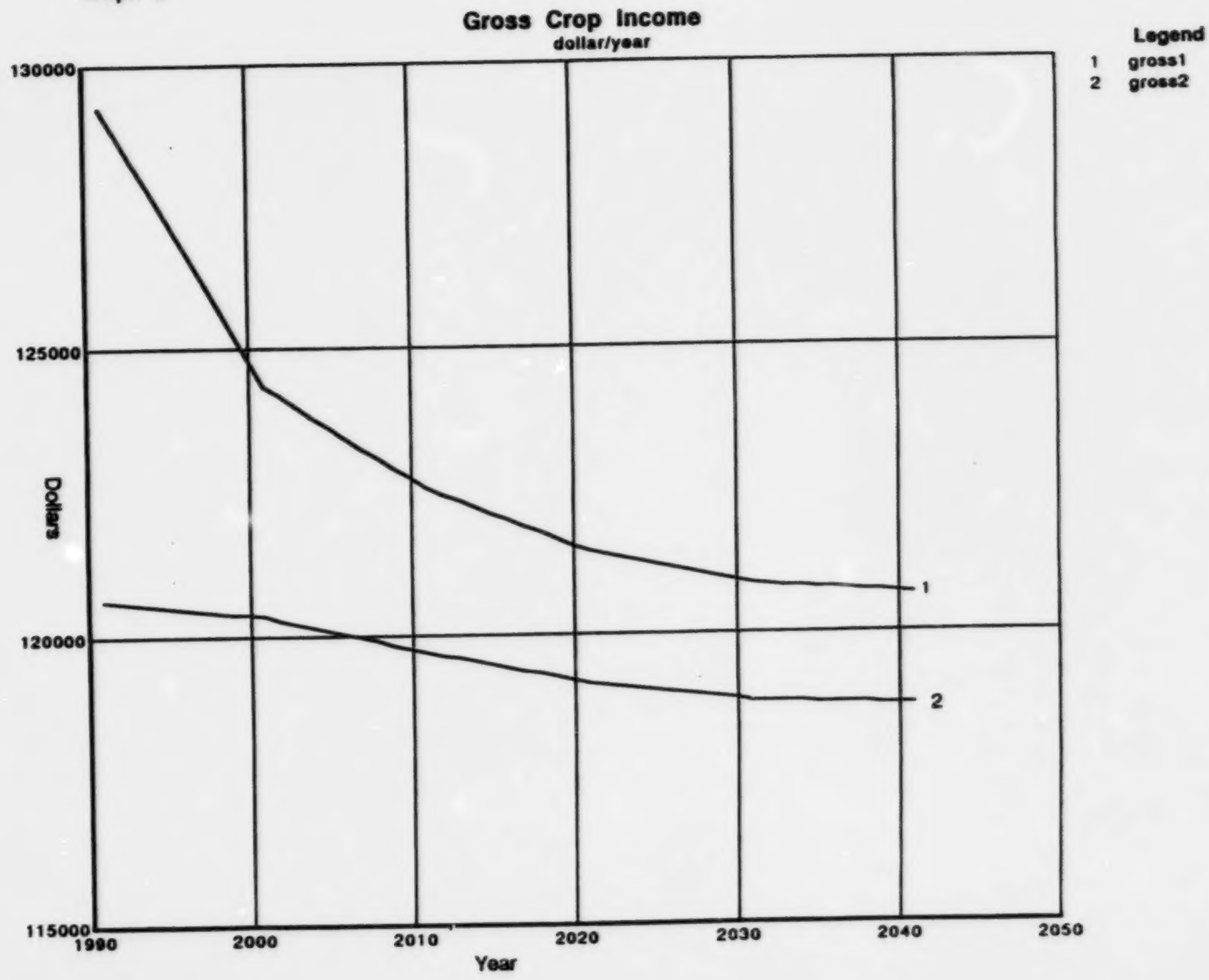
Graph 1


Field Elevation cross-section at x=250 meters
m1
Legend
fieldx1
1 field1
2 field2
3 field3
4 field4
field 3
field 2
field 4
field 1
Metres
Metres
0
10
20
30
40
0
100
200
300
400
500
600
700
800

Graph 2

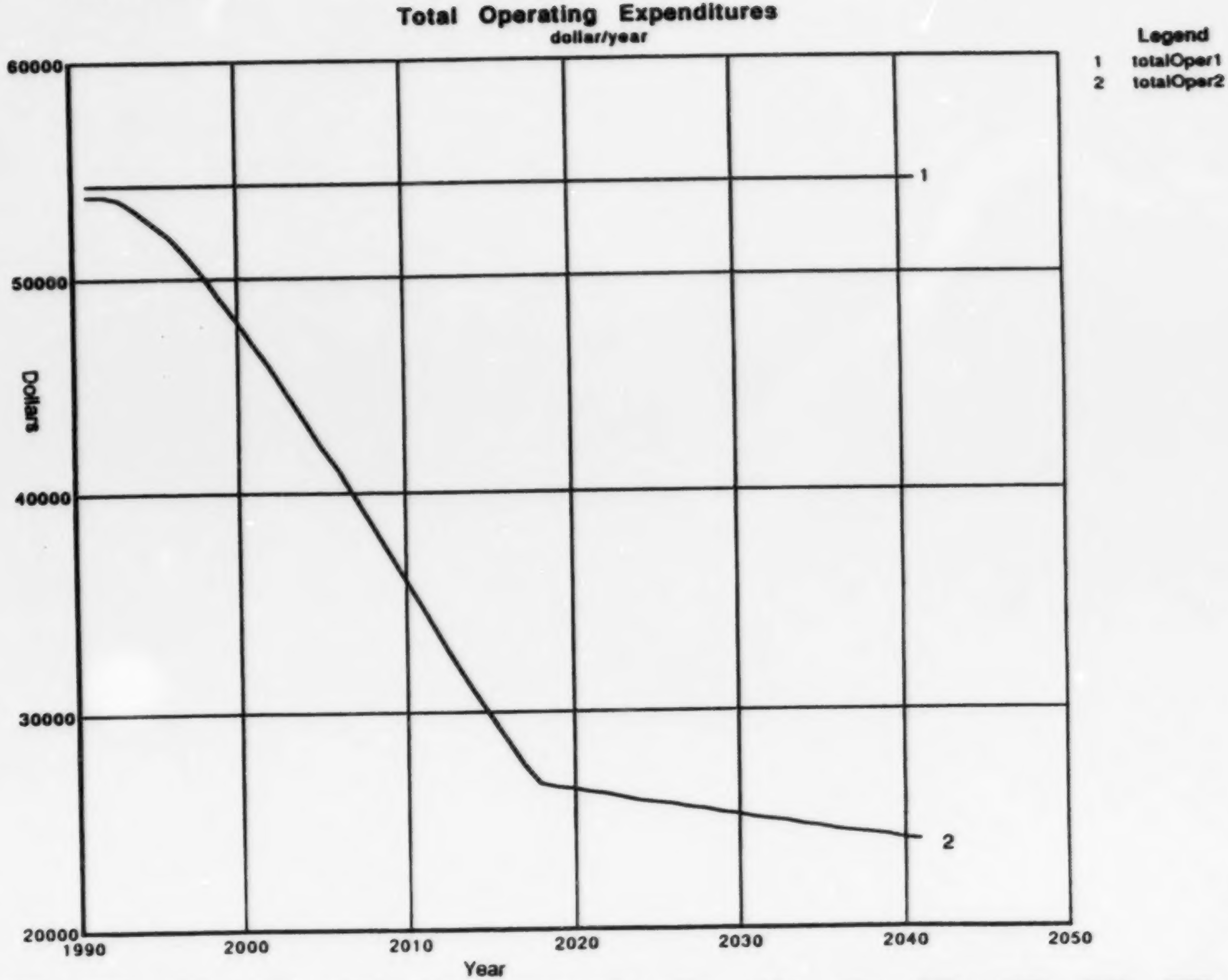
Field Elevation cross-section at y=400 meters
m1
30
20
10
0
Metres
0
100
200
300
400
500
Metres
1
2
3
Legend
fieldy1
1 field1
2 field2
3 field3
4 field4

Graph 3

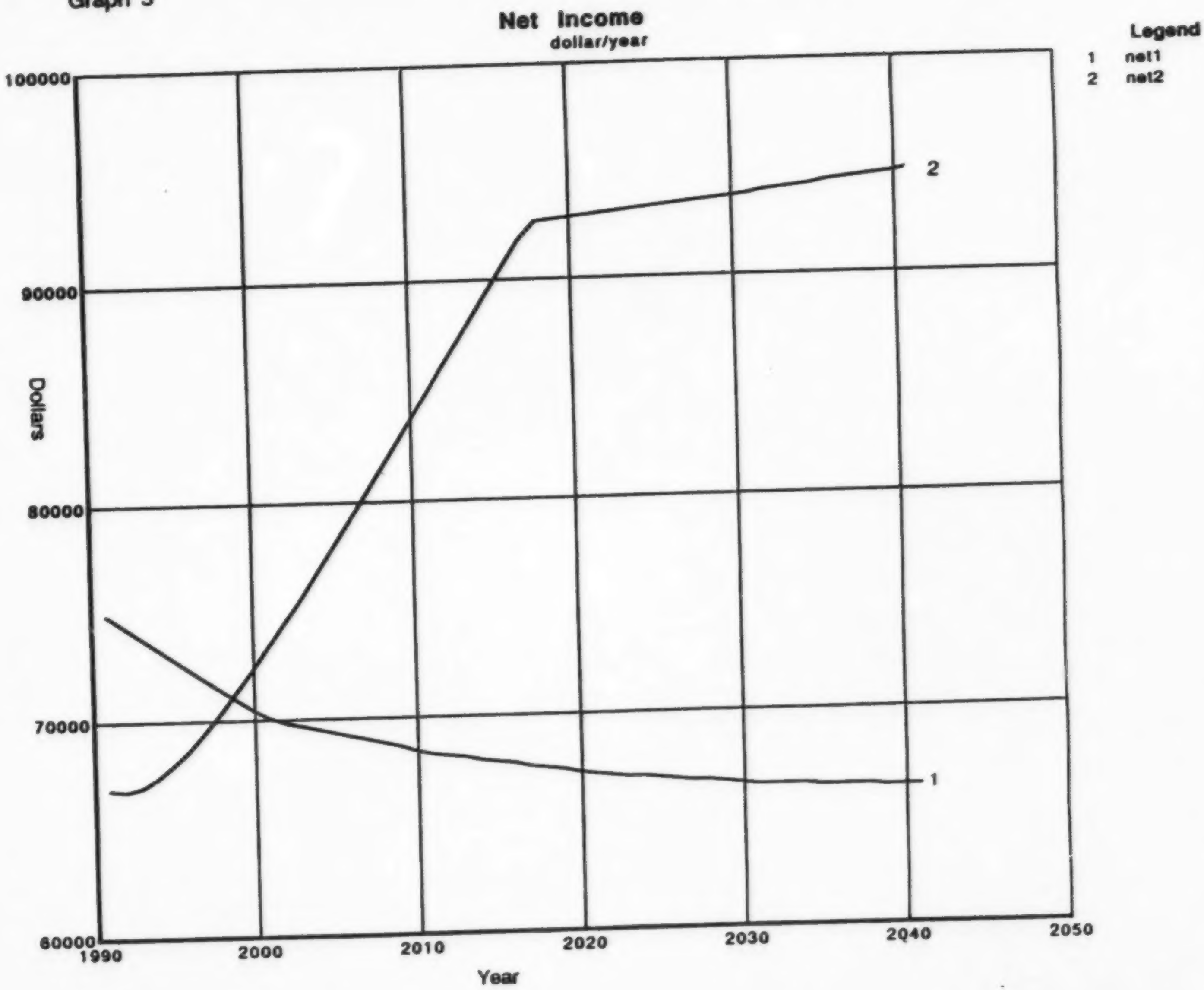


Gross Crop Income
dollar/year
Legend
1 gross1
2 gross2
130000
125000
120000
115000
Dollars
1990
2000
2010
2020
2030
2040
2050
Year
1
2

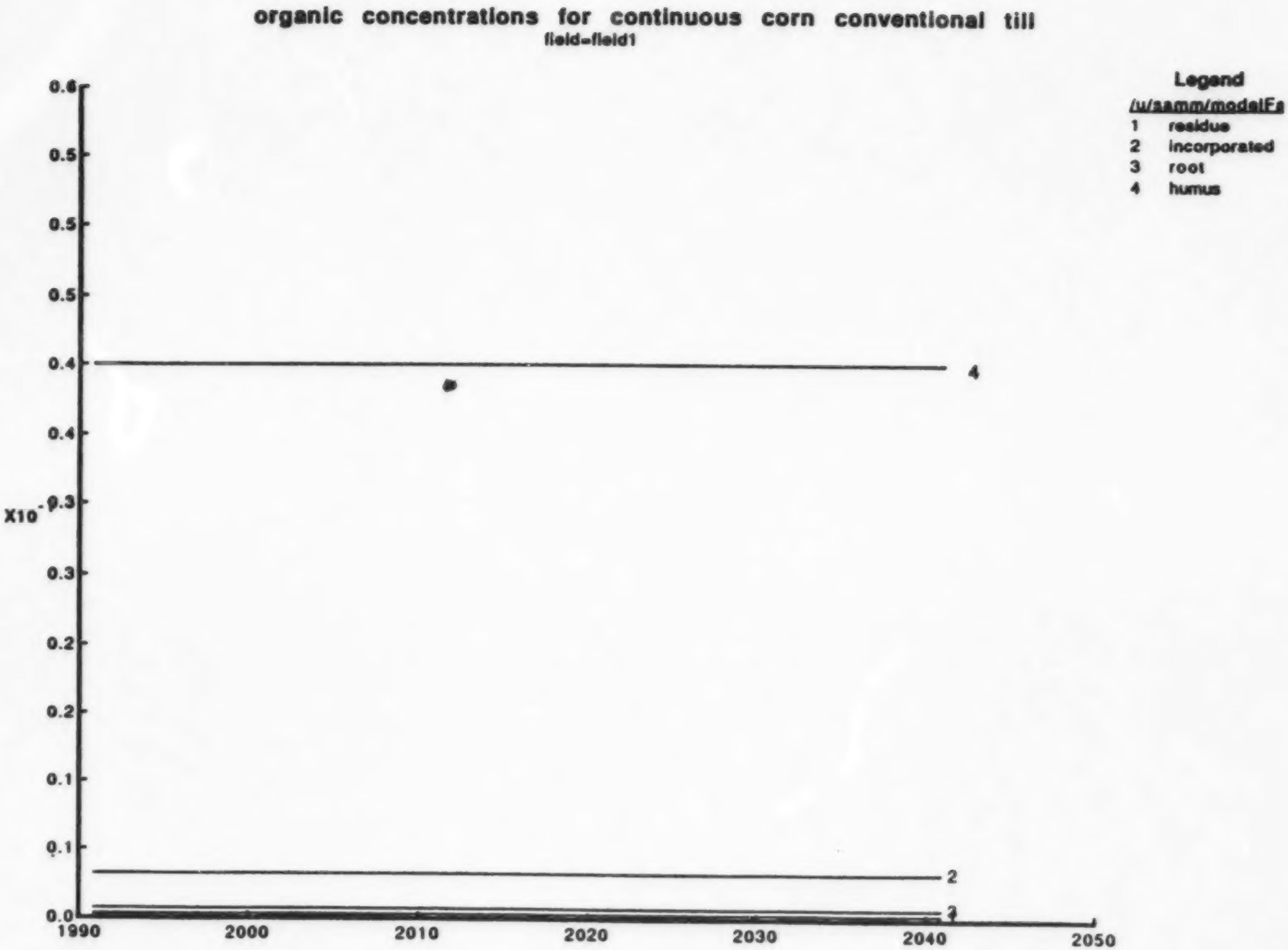
Graph 4


Total Operating Expenditures
dollar/year
Legend
1 totalOper1
2 totalOper2
Dollars
60000
50000
40000
30000
20000
1990
2000
2010
2020
2030
2040
2050
Year
1
2

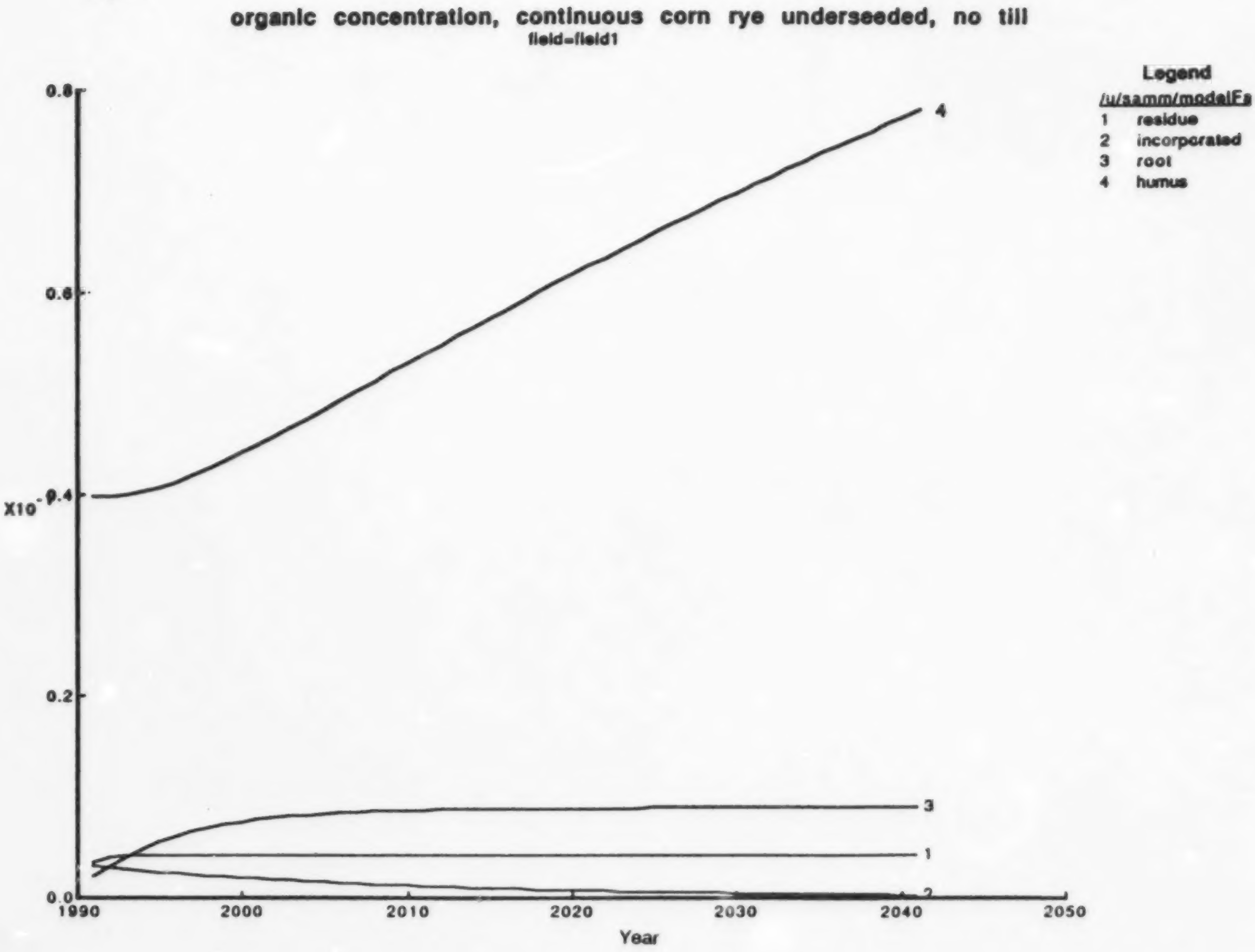
Graph 5


Net Income
dollar/year
Legend
1 net1
2 net2
Dollars
100000
90000
80000
70000
60000
1990
2000
2010
2020
2030
2040
2050
Year
1
2

Graph 6


organic concentrations for continuous corn conventional till
field=field1
Legend
/u/samm/modelFs
1 residue
2 incorporated
3 root
4 humus
0.6
0.5
0.5
0.5
0.4
0.4
X10^-0.3
0.3
0.2
0.2
0.1
0.1
0.0
1990
2000
2010
2020
2030
2040
2050
4
2
3
1

Graph 7

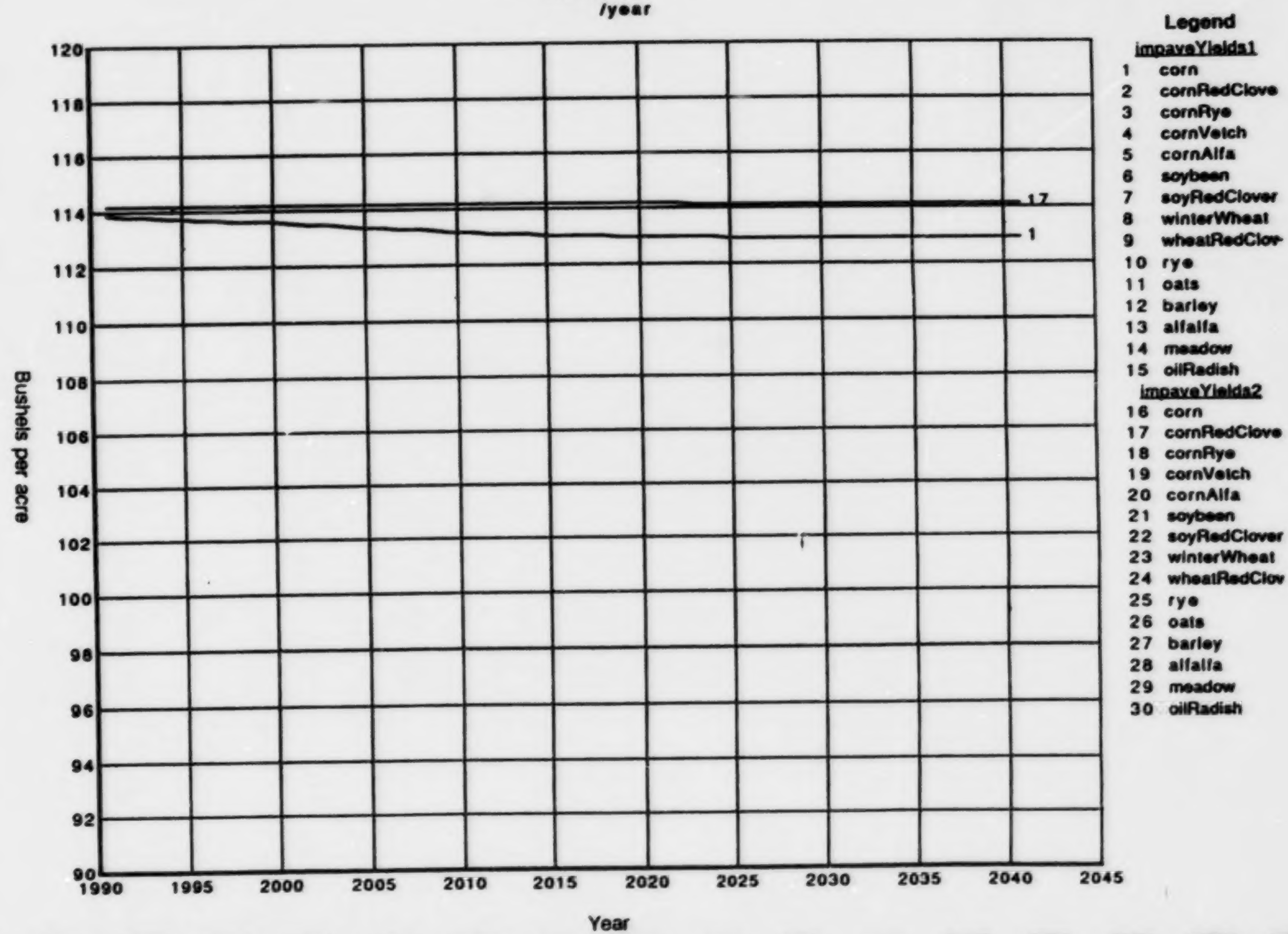

organic concentration, continuous corn rye underseeded, no till
field=field1
Legend
/u/samm/modelFs
1 residue
2 incorporated
3 root
4 humus
0.8
0.6
X10⁻ 0.4
0.2
0.0
1990
2000
2010
2020
2030
2040
2050
Year
1
2
3
4

Graph 8

Average Crop Yields (grains in bushels per acre, forages in tons per acre)

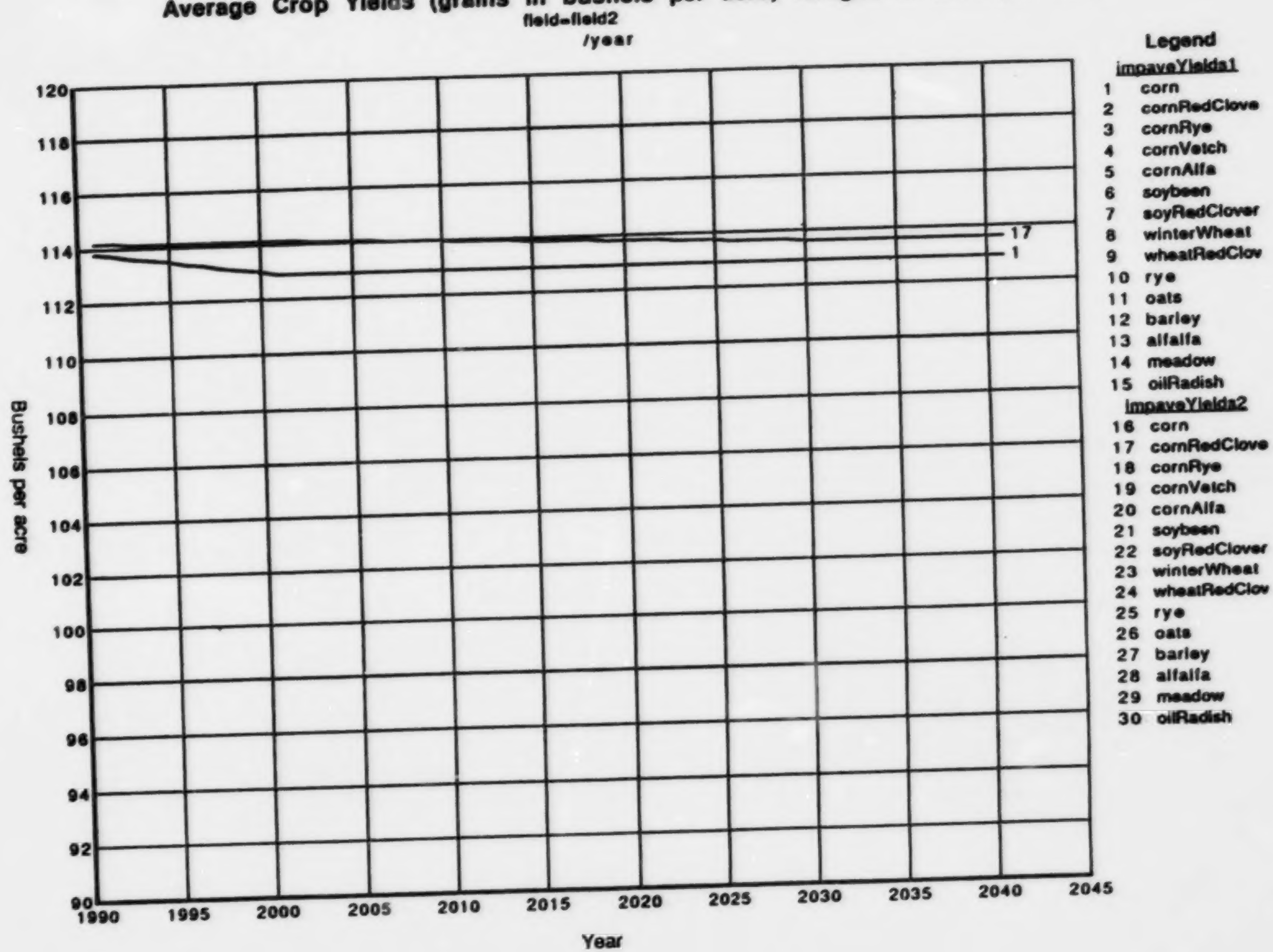
field=field1

/year

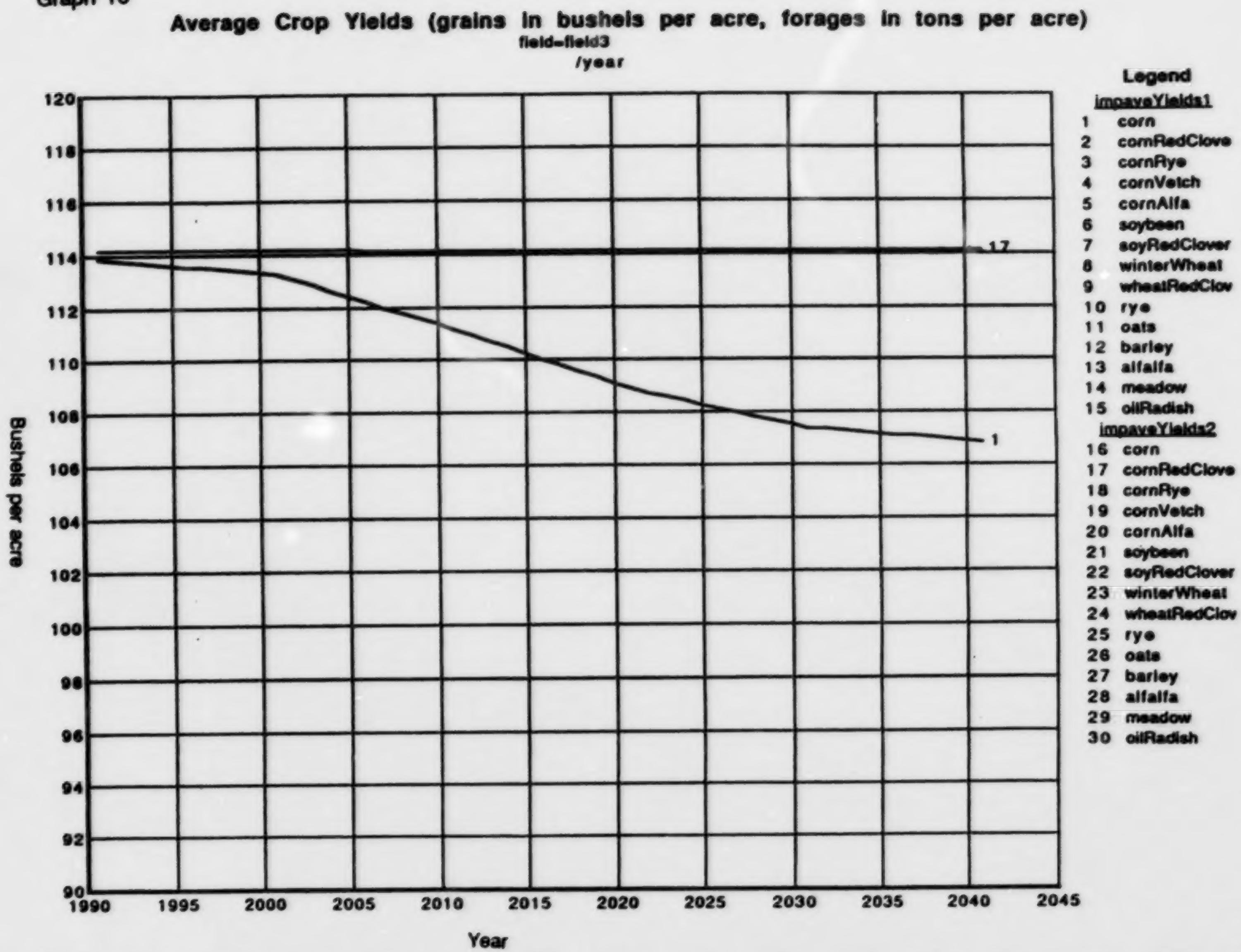


Graph 9

Average Crop Yields (grains in bushels per acre, forages in tons per acre)



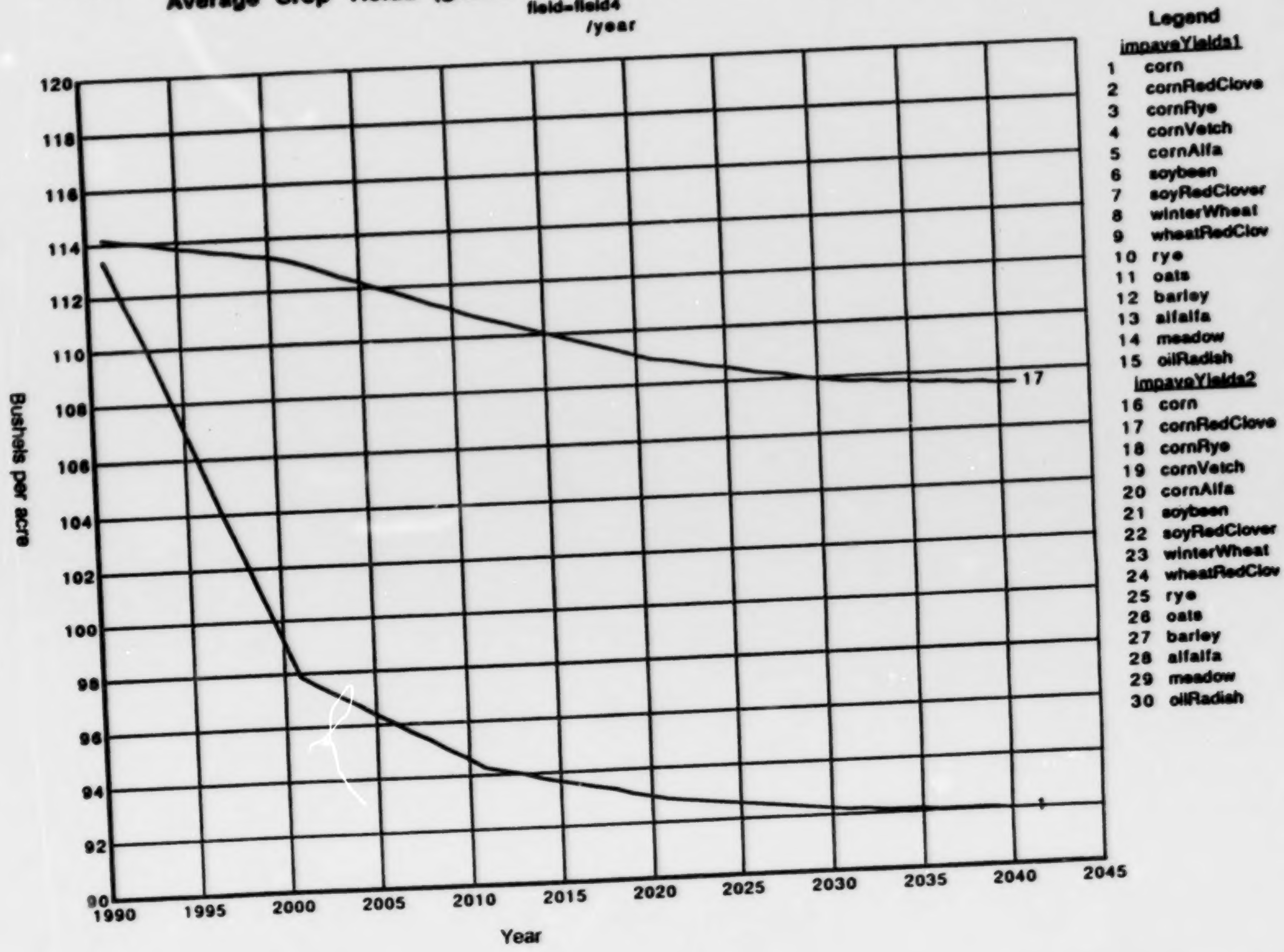
Graph 10



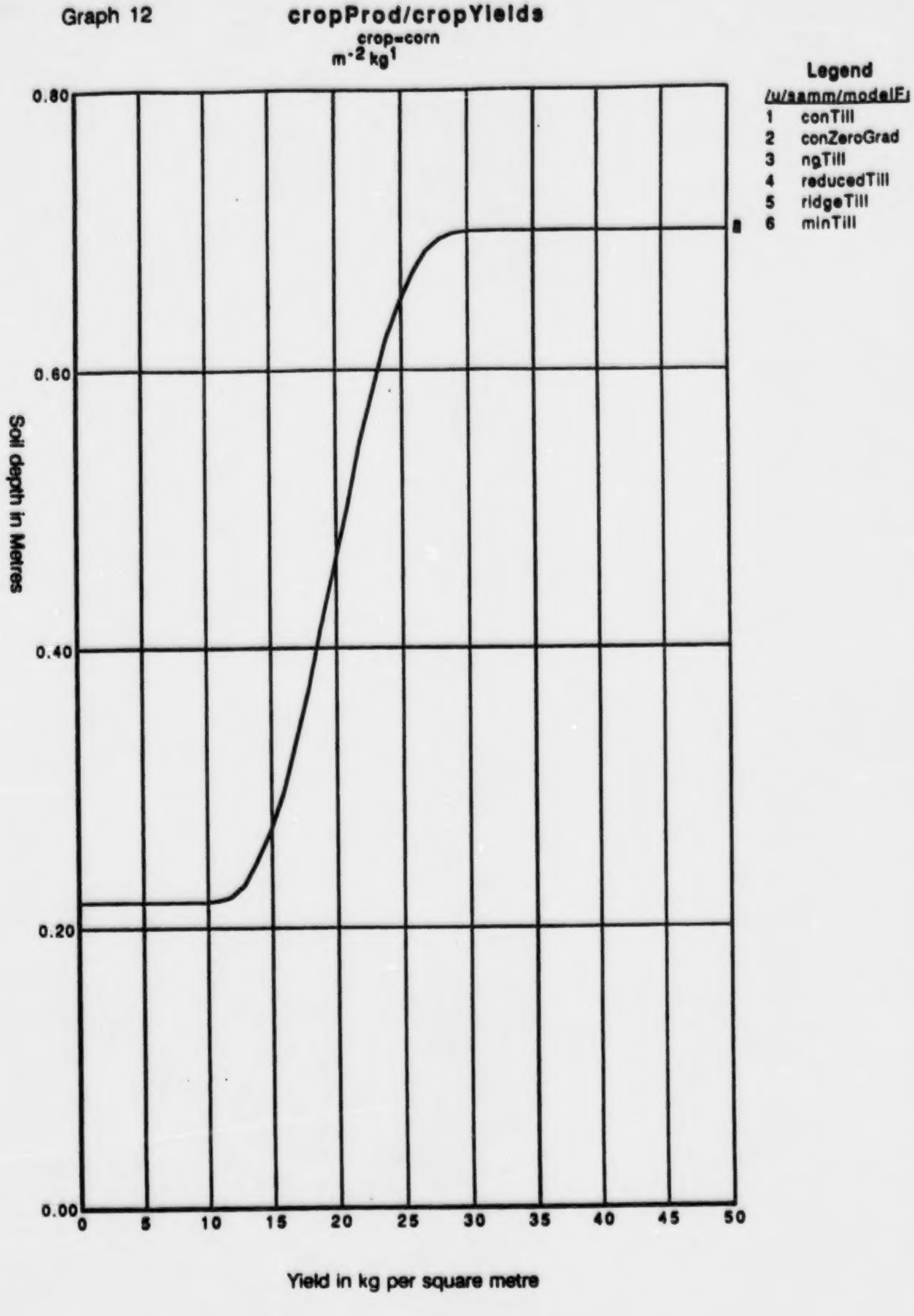
Average Crop Yields (grains in bushels per acre, forages in tons per acre)
field=field3
/year
Bushels per acre
120
118
116
114
112
110
108
106
104
102
100
98
96
94
92
90
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
Year
17
1
Legend
impaveYields1
1 corn
2 cornRedClove
3 cornRye
4 cornVetch
5 cornAlfa
6 soybean
7 soyRedClover
8 winterWheat
9 wheatRedClov
10 rye
11 oats
12 barley
13 alfalfa
14 meadow
15 oilRadish
impaveYields2
16 corn
17 cornRedClove
18 cornRye
19 cornVetch
20 cornAlfa
21 soybean
22 soyRedClover
23 winterWheat
24 wheatRedClov
25 rye
26 oats
27 barley
28 alfalfa
29 meadow
30 oilRadish

Graph 11

Average Crop Yields (grains in bushels per acre, forages in tons per acre)



Graph 12

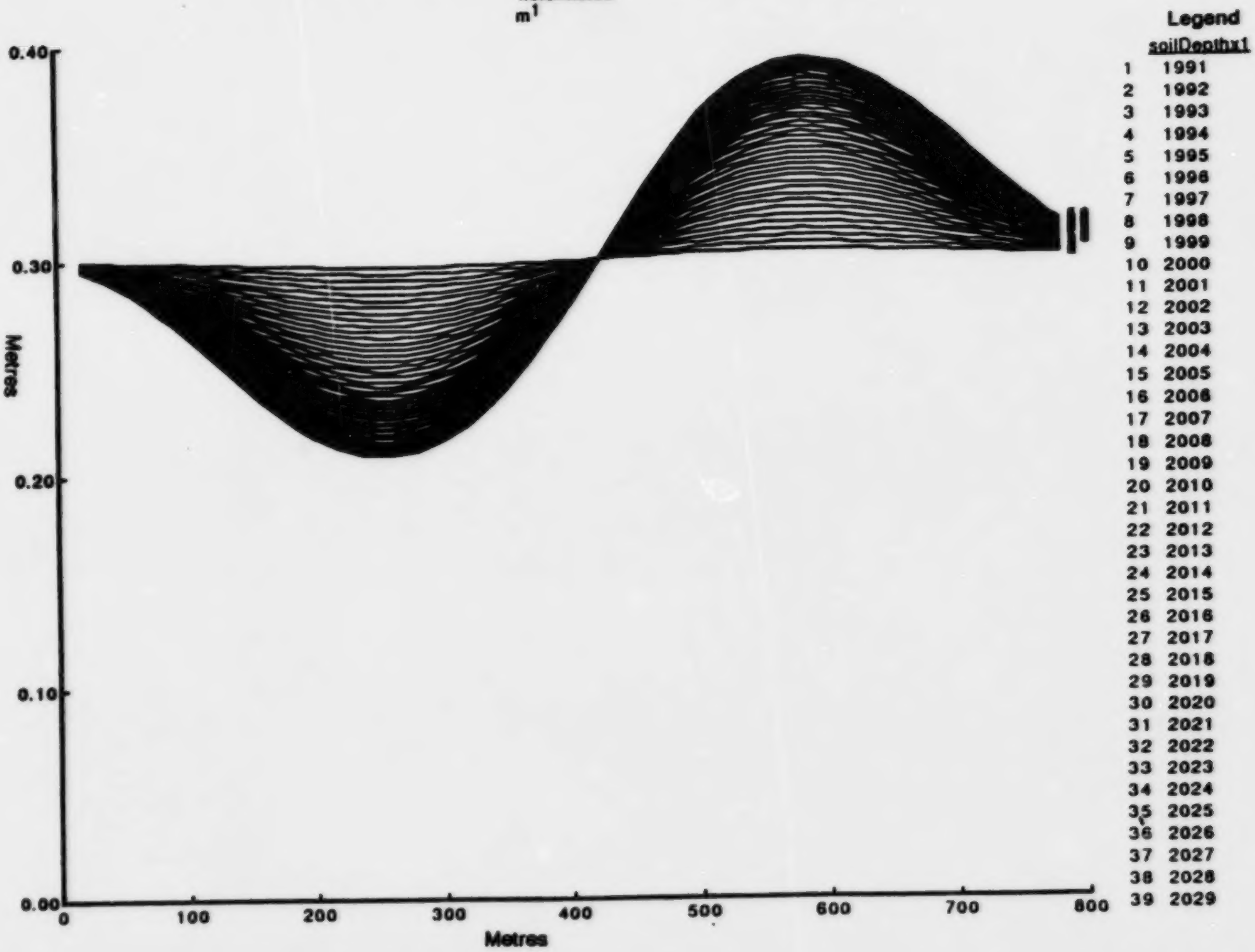

cropProd/cropYields
crop=corn
m-2 kg1
Legend
/u/samm/modelF:
1 conTill
2 conZeroGrad
3 ngTill
4 reducedTill
5 ridgeTill
6 minTill
0.80
0.60
0.40
0.20
0.00
Soil depth in Metres
0
5
10
15
20
25
30
35
40
45
50
Yield in kg per square metre

Graph 13

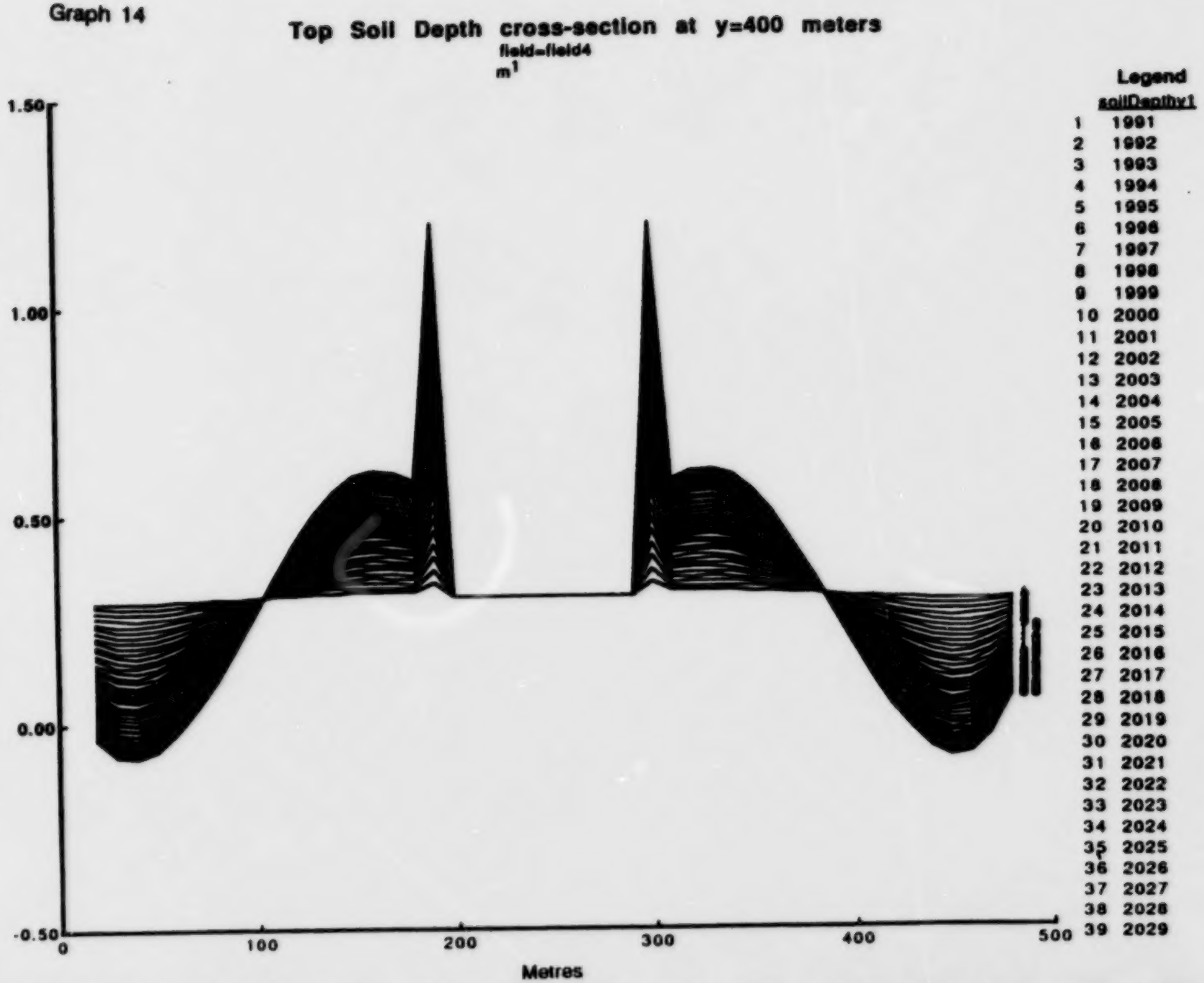
Top Soil Depth cross-section at x=250 meters

field=field3

m1

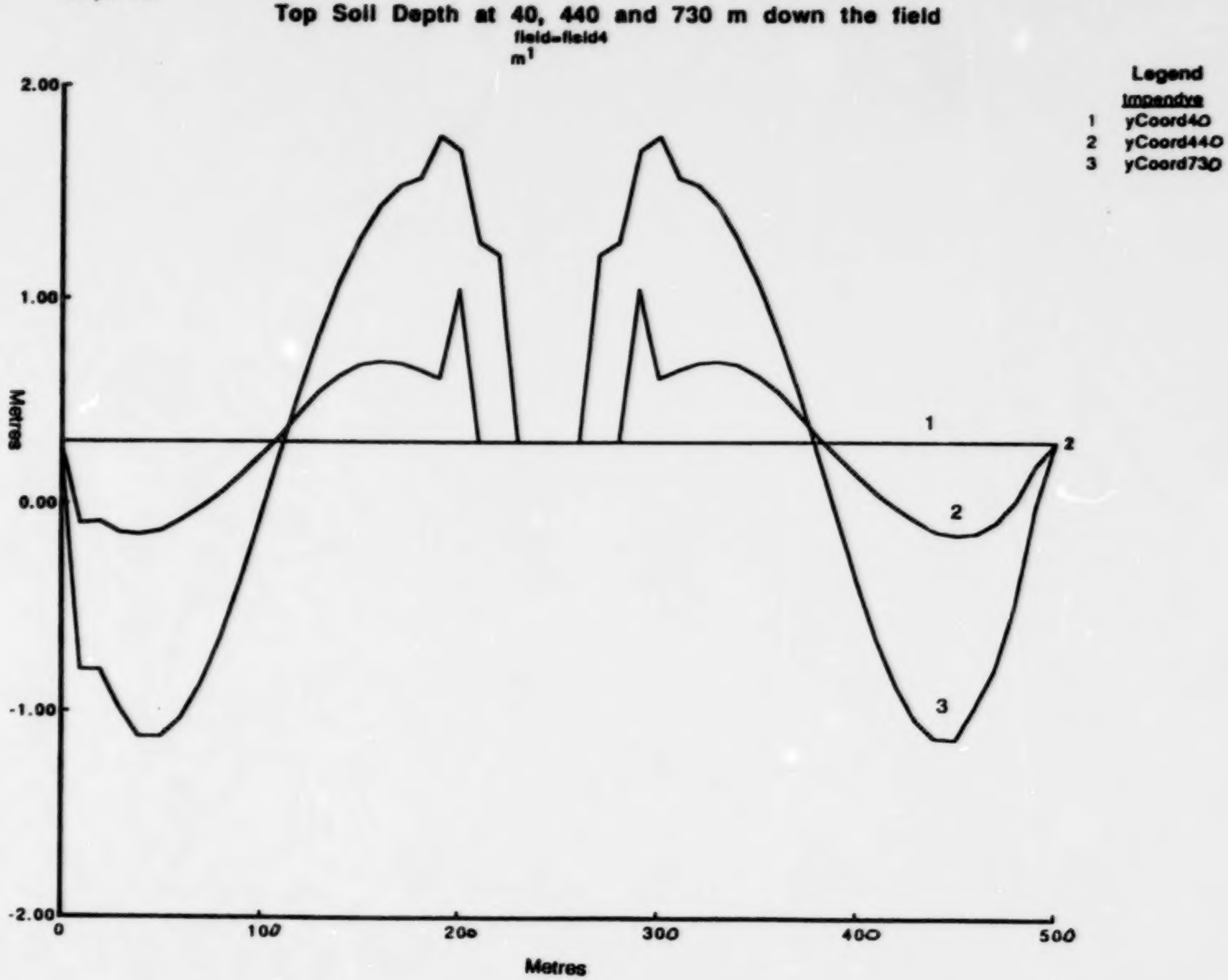


Graph 14



Top Soil Depth cross-section at y=400 meters
field=field4
m1
Metres
1.50
1.00
0.50
0.00
-0.50
0
100
200
300
400
500
Metres
Legend
soilDepthy1
1 1991
2 1992
3 1993
4 1994
5 1995
6 1996
7 1997
8 1998
9 1999
10 2000
11 2001
12 2002
13 2003
14 2004
15 2005
16 2006
17 2007
18 2008
19 2009
20 2010
21 2011
22 2012
23 2013
24 2014
25 2015
26 2016
27 2017
28 2018
29 2019
30 2020
31 2021
32 2022
33 2023
34 2024
35 2025
36 2026
37 2027
38 2028
39 2029

Graph 15


Top Soil Depth at 40, 440 and 730 m down the field
field=field4
m1
Legend
Impendve
1 yCoord40
2 yCoord440
3 yCoord730
2.00
1.00
0.00
-1.00
-2.00
Metres
0
100
200
300
400
500
Metres
1
2
3